

An Autonomous Telescope Implementation

at the

USQ Mount Kent Observatory

A Dissertation submitted by

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Abstract

Over the past decade, the quality and sophistication of optical telescopes commercially available has dramatically increased, with instruments in a class previously only within the reach of professional facilities now commonly possessed by advanced amateurs. A corresponding reduction in cost not only for these optical assemblies, but also for ancillary equipment such as high quality mounts, CCD cameras and computer hardware and software has meant that many areas of research, and in particular those appropriate for high school and university students, are now far more accessible than before, vastly increasing interest in the study of astronomy and astrophysics. At the same time, there has occurred a rapid expansion of the Internet, measurable in terms of its pervasiveness, richness of end-user experience and quality of infrastructure. The combination of these phenomena has meant that most of the issues that have stymied the development of remote and robotic observation have now been largely overcome.

Since early 2004, the author and co-contributors from the University of Southern Queensland's Faculty of Sciences have been developing a system for remote and robotic observation at the Mt Kent Observatory site near Toowoomba in South East Queensland, Australia. Reliable, online access to an observatory is provided, with students being able to conduct scientific-grade photometric and astrometric research using a system built primarily of commercial, off-the-shelf components. Further, fully automated observation is possible, meaning the user is no longer required to interact with the observatory directly, instead being only required to submit imaging requests and wait for their electronic delivery.

The various observatory components are described, example results presented and future directions and possible applications discussed.

Certification of Dissertation

I certify that the ideas, experimental work, results, analyses, software and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

Signature of Candidate

Dated this day of2010.

ENDORSEMENT

Signature of Supervisor(s)

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Dated this day of2010.

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Firstly, I am grateful to my supervisor Dr. Brad Carter, not only for his professional guidance and candor, but also for his unshakable faith in my ability to successfully complete this project in spite of my own uncertainty.

In addition, without the considerable contributions and dedicated commitment of my peers, the O'Mara Telescope at the USQ Mt Kent Observatory would not be the professional installation that it is today. In particular, I wish to thank Dr. Roy Duncan, Dr. Rhodes Hart and Bender Rodriguez whose combined enthusiasm and application of skills, often in the face of apparently insurmountable challenges, ensured our success.

Finally, to my wife Kirralee and daughters Sophie and Emily, I am eternally indebted for their understanding and on-going support, unselfishly relinquishing precious time that could otherwise have been spent together in order for me to complete this adventure.

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Chapter 1

Introduction

1.1 A brief history of robotic observation

The concept of remote and robotic telescopes has its genesis in the late 1970's during the period of initial adoption of microcomputers in the field of astronomy and astrophysics. Projects such as those initiated by Honeycutt et al. (1978) at the Indiana University to explore the application of computer controlled telescopes laid the foundation for landmark works such as *Microcomputer Control of Telescopes* by Truebold and Genet (1985). Limited by inadequate telecommunications infrastructure, most 'robotic' telescopes could only make use of emerging technologies on site, mainly for the purposes of target acquisition and tracking. Nevertheless, this was a vast improvement on traditional techniques, as electronic star atlases could be accessed in real-time when searching for objects of interest to the observer.

As discussed by Hayes and Genet (1989), the physical separation of astronomers from their observatories introduced a number of practical difficulties, but by abstracting observatory operations, astronomers could concentrate on more important research activities such as data reduction and analysis. It was soon apparent that the observatory would be required to have a high level of programmability along with a certain degree of 'awareness' in order to react to problems and make simple decisions in the event of abnormal conditions.

With these considerations in mind, the first protocol for robotic telescopic observation was developed by Hayes, Genet and Boyd and released in 1988. ATIS or the *Automatic Telescope Instruction Set* was a set of commands to be used for the control of unattended telescopes, accessory instruments and observatory infrastructure. For automated photometry for example, it could be used to open an observatory under suitable conditions, target the object of interest, make photometric measurements and return the system to its original state. It also provided mechanisms to detect and respond to error conditions and log all activity to a local computer. Because ATIS commands were constructed as a simple ASCII text file with a published extensible instruction set, it was also possible to share observing ‘plans’ between researchers regardless of the underlying physical implementations of their equipment. Moreover, perhaps the most powerful ability of ATIS was that over time, its continued development finally yielded at least a partial solution to the problem of efficient job scheduling (Henry 1996).

As technology improved and became more available to the amateur astronomer, so too did the demand for automation and remote control of their equipment. Computers in the home environment were becoming commonplace and astronomy was an obvious application of this newly accessible technology, providing the ability to acquire and analyze large amounts of useful scientific data.

While large research facilities could allocate significant resources to the task of automating CCD-equipped telescopes of the day, the amateur (and indeed less well funded professional observatory) often possessed capable equipment, but no cost-effective method of implementing automation. Economies of scale quickly provided a solution, and a market rapidly developed for those willing to devote time and effort in the hope of a return more than the personal satisfaction of achieving robotic operation of their own equipment.

Commercial applications useful to astronomers were widely available by the mid-1990's, and the telescopes available at the time were becoming more and more advanced, not only being electronically controlled but also having the ability to interface with personal computers and the software which ran on them.

With the expansion of the Internet, remote operation of high-quality, low-cost astronomical equipment was now possible, astronomers being able to use a telescope anywhere in the world in real-time, limited only by their ability to access some interface to it.

By this time, ATIS had failed to keep up with increasingly feature-rich commercial offerings, perhaps due to the apparent disappearance of its creators from the development scene. Few other options were immediately available and while there was little doubt that open source approaches had merit, a lack of ongoing dedicated support and a common direction limited adoption on a large scale.

In late 1998, Bob Denny of DC-3 Dreams released Astronomer's Control Panel (ACP1), software that ran under the popular Microsoft Windows operating system and provided full functionality via a personal computer interface to the Meade LX200 Classic. Not only could it be used to remotely (and therefore possibly *robotically*) control the LX200, but it also allowed other applications to utilize this capability as well by employing the open Windows Scripting interface at its core.

In mid-2001 the first ASCOM (AStronomy Common Object Model) platform was released simultaneously with an updated version of ACP, whereby the functionality of individual components could be abstracted in client-hardware interaction. ASCOM was open source, allowing anyone to write driver software for any device, the only limitation being that it required the software to run in a Win32 environment. Over time, not only has ASCOM provided drivers for telescope control, but also for the majority of

accessory devices (such as CCD imagers, focusers, etc.) that are a prerequisite for the successful implementation of an automated observatory such as the one described here.

ASCOM can be regarded as the glue that enables the components of the observatory to operate together seamlessly. It promotes the construction of complex relationships between software and hardware without the need to design APIs specific to individual elements, which too often has been the limiting factor in the development of a working implementation.

1.2 The USQ Mount Kent Observatory

The Mt Kent Observatory (MKO) has been operated by the University of Southern Queensland since July 1996 for the purposes of teaching and learning along with community outreach. It is located approximately 30km from the regional city of Toowoomba, population approximately 100,000 (ABS 2008), in South-East Queensland, Australia. At an altitude of 673m and latitude of 27°47'S, the local area experiences an average of 114 clear days per year (BoM 2007) based on data recorded at the nearby Oakey station (ICAO code YBOK) from 1957 to 1998.

The monthly distribution of clear days is favorable to observation during the cooler winter months.

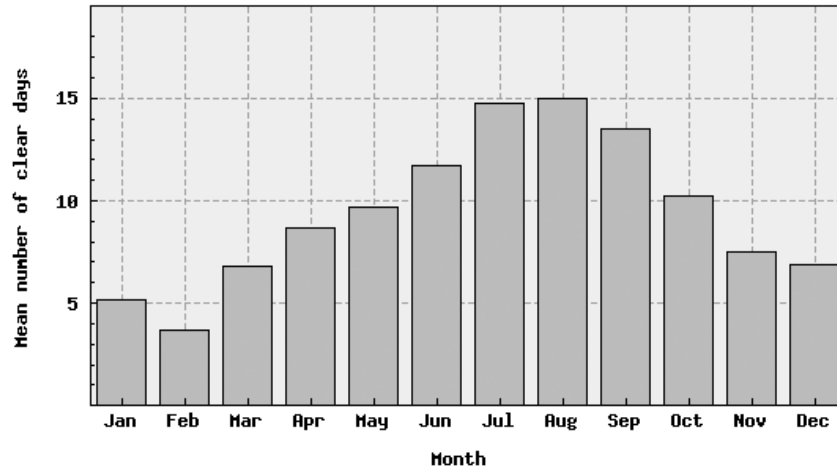


Figure 1.1 Mean clear day distribution for Oakey station. (BoM 2007)

A combination of an average yearly rainfall of approximately 950mm which is primarily concentrated on the summer months (BoM 2007) and generally stable atmospheric conditions result in seeing at the site being typically observed at around two arc-seconds, improving to arc-second quality under ideal circumstances. Figure 1.2 shows the mean rainfall distribution for the years 1869-2007:

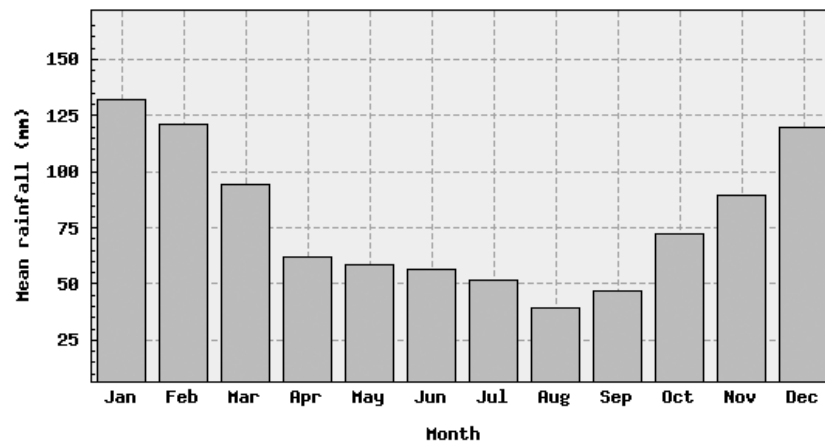


Figure 1.2 Mean annual rainfall distribution at Oakey station. (BoM 2007)

Measurements collected by the on-site weather station over the period 2005-2009 reflect this historical data, both in relation to the number of seasonal clear days and average rainfall.

The impact of human activity on the night sky is evident, with the urban development of Toowoomba being the primary source of light pollution and atmospheric aerosols, but since the construction of the observatory, this has not increased to an extent that has significantly reduced or otherwise limited on-going activities.

There have been several studies carried out in the past to determine the suitability of Mount Kent for observations by small and medium class optical telescopes. Moller (1996) determined a mean seeing value of 1.22 arc-seconds for the site, based on a limited observation period of only three nights during the Autumn/Winter period.

This value is similar to that experienced at other observatories located in Australia such as Siding Spring (MPC Observatory Code 260) with Wood, Rodgers and Russell (1995) arriving at a value of 1.2 arc-seconds for that location.

Access to the MKO is by sealed road, with modern facilities providing necessary support infrastructure for the university's teaching and research activities.

There are three dome structures at the site, along with the Educational Development Group (EDG) building which acts as the central focus for accommodation and network infrastructure, as well as a local control room for the operation of any of the telescopes at the facility. Network connectivity is provided by microwave link to the main university campus in Toowoomba and is capable of 22Mbit/sec connection speeds, with gigabit fiber available from there to the Internet.



Figure 1.3 The Mount Kent Observatory site looking West (Carter 2008).

Local weather data is collected at the EDG building by an automatic weather station, and details of the current conditions are made available in real-time via publicly accessible web pages or for autonomous agents such as monitoring equipment.

The site supports visual observation, using small manually operated telescopes as well as hosting two robotic systems. Since 2004, two projects have been underway to develop fully automated observatories, one in partnership with the University of Kentucky in the United States (<http://orion.mko.usq.edu.au/telescopes/UofL/index.html>) and the second (the O'Mara Telescope) which is described in detail here.

1.3 Aims and Objectives

This project aims to develop a small, automated CCD-equipped observatory suitable for, but not limited to, the study of young rapidly rotating stars, extra-solar planet candidates and potentially hazardous near-earth objects by research students of the University of Southern Queensland. Specifically the projects goals are:

1. Design and implement an automated optical observatory that can capture images of user-selected targets and deliver them with sufficient photometric and astrometric quality and in such a timely manner to allow effective research.
2. Maximize the efficiency of the system by employing a suitable user interface and scheduling methodology.
3. Minimize system downtime, by way of careful evaluation, selection and installation of the various hardware and software components.

Additionally, the capabilities of the system shall meet the following technical requirements:

1. Be able to image objects between a minimum altitude of 30° and maximum altitude of 80° regardless of azimuth.
2. Have a limit of resolution that exceeds the average seeing value at the installation site, and an effective limiting magnitude of at least 18.

This project tests the hypothesis that an automated (robotic), remotely operable observatory capable of supporting scientific research can be cost effectively implemented using commercial, ‘off-the-shelf’ components. Further, by limiting the requirements of the observatory to a few specialized functions that can be applied to a variety of research activities, the chances of long-term success should be greatly improved. Validation of this approach offers educational institutions (especially those engaged in distance education) an effective way to incorporate research projects in astronomy and astrophysics into undergraduate and postgraduate education, and expands the range of institutions, groups

and individuals who can incorporate observational research in their activities.

Further to this, if a proven and repeatable recipe is developed according to these principles, collaboration with other educational institutions becomes much easier, and the issues of design, implementation and future support are greatly simplified. This result can only encourage the wider adoption of such technology to enhance teaching and learning at all levels, but especially so in the secondary and tertiary education sectors.

Chapter 2

Method

In essence, this project is one of integration, by way of testing, evaluating and implementing off-the-shelf components where possible in order to meet a set of defined objectives. In order to achieve this, the goals outlined were first converted to a set of high-level tasks that would satisfy each of them. When looked at in this light, the completed project consists of following activities:

1. **Audit** the current hardware and software components of the O'Mara telescope.
2. **Design** a new system or modify the one in place.
3. **Implement** the proposed solution.
4. **Test** the actual system that is installed.
5. **Evaluate** objectively how well the system performs.
6. **Improve** if required.

At the commencement of the project, the O'Mara Telescope comprised of a Celestron C-14 Schmidt-Cassegrain optical tube assembly attached to a Software Bisque Paramount ME German Equatorial mount. This combination was housed in the 2.3m central dome enclosure and had been assembled by previous students and USQ staff with the intention of developing an automated system. A series of on-going problems had meant progress had stalled in achieving the intended goals, with the most important obstacles encountered being summarized as:

- Poor pointing accuracy and repeatability of the Paramount ME mount
- Apparent inaccurate tracking performance of the Paramount ME mount
- Development of a suitable Internet-accessible control interface

- No way of efficiently scheduling observations

Based on a detailed analysis of the pointing and tracking issues encountered which were similar to experiences of the author at another installation (MPC E25 – APTA Rochedale), it was proposed that the 14” Celestron was the most likely source of the errors displayed as the focusing mechanism had been heavily modified in an attempt to reduce ‘mirror-flop’.

In order to determine if the Celestron was indeed the problem, it was removed, a small refractor attached to the mount in its place and a series of pointing tests performed using a webcam attached directly to the eyepiece. As a result of these tests, it was established beyond doubt that the majority of problems with the original configuration could be attributed to the C-14, presumably related to the modifications to the mirror mounts and focuser as mentioned earlier.

At this point the decision was made to replace it with a smaller known-good 12” Meade of similar Schmidt-Cassegrain design. This would be a significant reduction in aperture, but being able to perform the task of robotic observation, even with a reduced set of available targets, was the over-riding consideration.

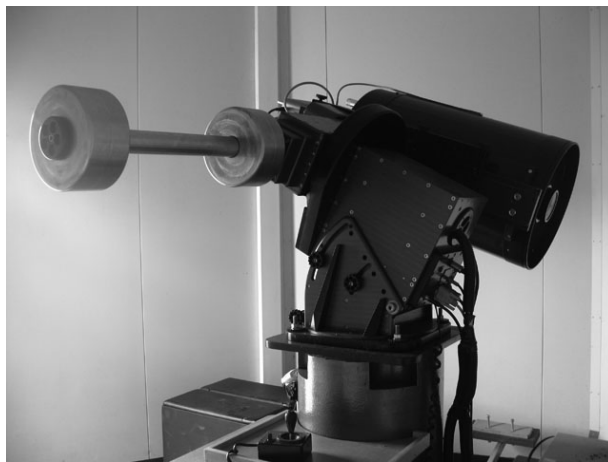


Figure 2.1 The O'Mara Telescope.

2.1 The Mt Kent O'Mara Telescope System

The O'Mara Telescope at the Mount Kent Observatory is made up of a number of sub-components linked together to make up the system. Each element has been chosen based on a variety of factors, including previous experiences, existing performance, budget limitations and future capability. They can each be regarded as part of the overall process in the construction of the working observatory and as such shall be described in detail separately.

Numerous attempts have been made to implement automated observatories in the past, and in most cases where success has not been achieved, the problems have often been traced back to trying to reinvent the wheel and solve a myriad of complex tasks in-house.

In this project, the task was not to construct new components to meet the aims and objectives outlined, but rather to reach a solution through the careful selection, evaluation and integration of existing hardware and software available that were able to perform tasks individually.

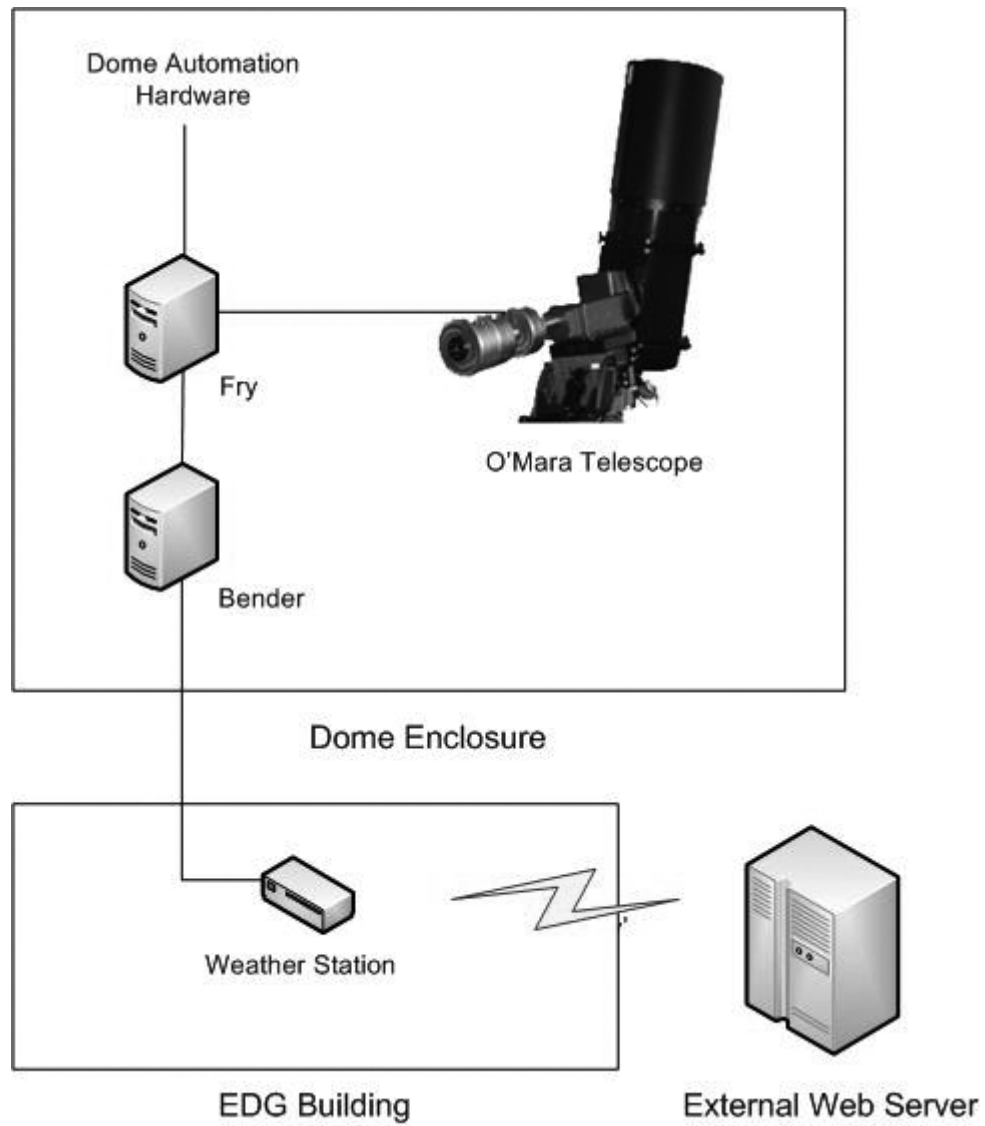


Figure 2.2 An overview of the O'Mara Telescope System.

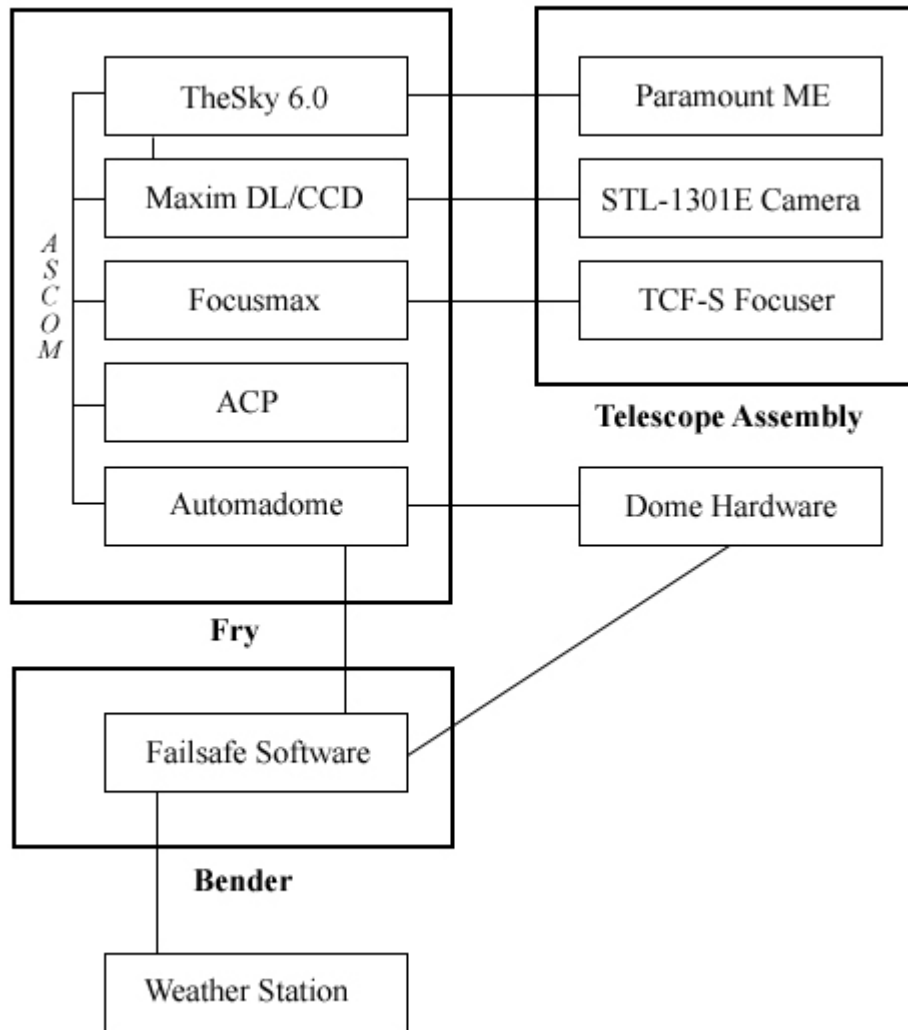


Figure 2.3 Block diagram of the relationships between the components.

The majority of hardware and software used are physically located within the dome structure housing the O'Mara telescope itself, with the exception of the weather station and associated sensors (located atop the EDG building) and the Internet-accessible web server (currently housed at the University of Queensland in Brisbane, Australia).

2.2 The Mount

The primary purpose of any telescope mount is to accurately point the optics and imager at a desired target with repeatable accuracy. In the case of extended imaging (be it photographic or by CCD), it must also track this target for the exposure duration, countering the effects of the Earth's rotation and introducing as few inaccuracies as possible, thereby maximizing the quality of the data acquired.

The Paramount ME is a commercial computer-controlled German Equatorial mount manufactured by Software Bisque of Golden, Colorado in the United States. It is marketed as a research-grade, high quality mount and is widely used at numerous observatories around the world. With a claimed maximum 7 arc-second peak-to-peak periodic error, it was purchased by USQ in 1998 to provide a solid foundation to robotic observation projects. After periodic error correction the mount allows for unguided exposures of up to 300 seconds in its current configuration, and combined with the CCD imager employed, enables the system to reach a limiting magnitude of around 19 under ideal conditions.

The mount does have some important limitations, most notably an inherent inability to be controlled by any software other than that which it is packaged with, "The Sky Version 6.0", at present only being implemented on the Microsoft Windows operating system.

2.3 The Telescope Optics

As mentioned, when initially evaluated it was evident that the existing system was unable to accurately point with any degree of repeatability. Many hours of troubleshooting were carried out by staff and students of the university with little progress, on the assumption that the Paramount ME was the cause of the problems, due to either software issues or the mechanical characteristics of the mount itself.

Pointing errors that were not only of varying magnitude (up to 3 degrees), but also not predictable based on the area of the sky being observed (i.e. being dependent upon the orientation of the mount) were observed, and these would become apparent with no obvious pattern.

The designs of the majority of modern, commercially available Schmidt-Cassegrain telescopes typically employ a primary mirror that is mounted on a suspended cell (see Figure 2.4), moved in relation to the secondary mirror to achieve focus. Under normal circumstances such as during visual observation, this does not generally cause a problem, as any image shift is compensated for by the observer. For automated observations, which have far greater accuracy requirements along with extended exposure times, the mirror must remain suitably fixed at all times and in an attempt to achieve this, the existing 14" Celestron SCT had been retro-fitted by the USQ mechanical workshops with a locking mechanism to prevent movement of the mirror cell at all orientations.

Since the modifications that had been carried on the optical tube assembly were undocumented, it was impossible to determine the extent to which they may have contributed to the errors observed. It was decided that instead of continuing with the current investigation, it would be better to replace the Celestron with a small refractor, thereby removing the complicated light paths and mechanical properties of the Schmidt-Cassegrain design. Once this telescope was installed, practically all of the errors previously encountered immediately disappeared, with performance of the system being observed at or very near to what was expected.

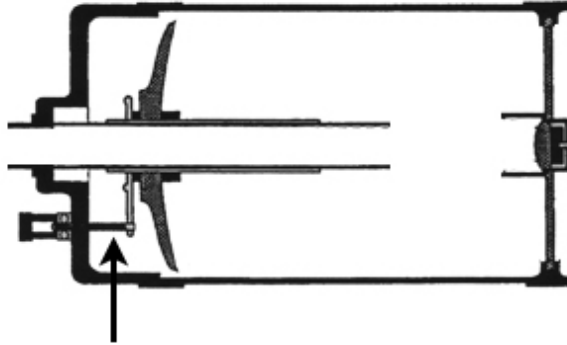


Figure 2.4 The schematic layout of a typical commercial SCT, with the arrow indicating the focuser mechanism.

With the knowledge that the Paramount ME was performing to specification, and that the Celestron 14" was no longer usable for the project, a smaller replacement Meade 12" SCT was sourced and attached for testing. This telescope is equipped with a locking mechanism as part of its design and when used in conjunction with the mount and associated hardware, appeared to resolve all of the issues previously encountered.

This action meant a re-evaluation of the original goals of the project, with the reduction in telescope aperture from 14" to 12" having the potential to affect the number of targets that would be available to the observatory for research. The first critical attribute of the observatory affected by this change was *Light Gathering Power*, which is proportional the total surface area of the primary mirror. Since telescope objectives are typically circular, the area can be specified in terms of aperture (d) being the diameter of the objective:

$$A = \frac{\pi}{4} d^2 \quad (1)$$

It follows then, that the L.G.P. increases as the square of the aperture. The comparison in light gathering power between the two telescopes available for the project can be expressed as:

$$\frac{A_{Celestron}}{A_{Meade}} = \frac{\frac{\pi}{4} 14^2}{\frac{\pi}{4} 12^2} = \left[\frac{14}{12} \right]^2 = 1.36x \quad (2)$$

This meant that by installing the Meade 12", the observatory would see approximately a 25% reduction in light gathering power. This obviously would affect overall performance for the purpose of research and therefore needed to be considered carefully before a final decision was made. To replace the 14" with another optical tube of similar specifications would also impose an additional capital expense in the order of A\$7,500 which was beyond the budget of the project.

The next issue to be addressed was to what extent the *Resolving Power* of the system would be changed. It is derived from the Dawes limit:

$$\alpha = \frac{4.56}{D} \quad (3)$$

where α is the resolving power in arcseconds and D is the aperture, in inches. Provided this value remained below the effective seeing limitations of the site, there would be no impact on the performance of the system. When considering the two available telescopes with values of 0.32 arcsec for the C14 and 0.38 arcsec for the Meade, there would be little effect as seeing would likely never approach these values.

In the end, it was concluded that there was not enough of an impact in any of these areas to justify the expenditure when the 12" was immediately available at no cost and so was installed.

2.4 The CCD camera

Imaging is accomplished by way of a SBIG STL-1301E CCD camera with array of 1280 x 1024 pixels. Operating at f/10, this configuration provides an effective field of view of 23.084 x 18.467 arc seconds with an imaging resolution of 1.082 arc seconds per pixel. Integral to this camera is a five position filter wheel housing research-grade 2" Johnson/Bessell UBVRI glass filters. The high quantum efficiency of the device (see Figure 2.5) in this camera allows for an effective limiting magnitude for CCD observations (up to 300 seconds) of approximately 19.5 before image quality is reduced due to electronic noise etc. The technical specifications of the STL-1301E when attached to the optical tube assembly are presented below:

CCD Format	1280 x 1024 pixels
Pixel size	16 microns
Telescope Aperture	304mm
Operating Focal Ratio	10
Focal Length	3040mm
Image Scale	1.082 arc seconds per pixel
Field of view	1385" x 1108"
	23.08' x 18.46'
	.385 x .308 degrees
<p><i>Notes : Formula for radian measure in terms of radius (r) and arc length (s)</i> <i>Pixel scale = 206,265 arc seconds x pixel size/focal length</i></p>	

Table 2.1 Optical specifications of the O'Mara Telescope.

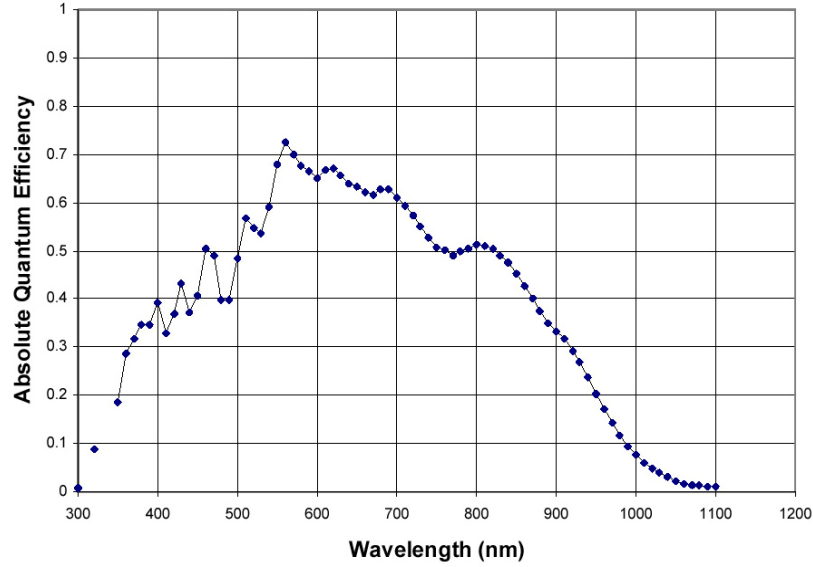


Figure 2.5 Quantum Efficiency of the KAF-1301E CCD (Source: Kodak).

The most reliable method to measure a CCD camera's performance is to evaluate the total signal to noise ratio of the system, which is given by the well known "CCD equation"

$$S/N = \frac{N_*}{\sqrt{N_* + n_{pix} (N_s + N_d + N_r^2)}} \quad (4)$$

The individual terms are N_* , the total (sky subtracted) number of photons from the source; n_{pix} , the number of pixels contained within the aperture; N_s , the total number of sky photons per pixel; N_d , the total number of dark current electrons per pixel and N_r , the read noise in electrons per pixel. As noted by Howell (1989), for the majority of modern CCD devices, the dark current is negligible to the extent that it may be safely ignored.

Evaluation of equation above, with parameters taken from the aims and objectives of the project mentioned previously, result in the following values for the O'Mara telescope for exposure times of 60, 90 and 180 seconds:

Filter:	V	Telescope_diameter:	306 (mm)
Overall QE:	0.7	Pixel size:	1.082 (arcsec/pixel)
Airmass:	1.2	Exposure times:	60, 90, 180 (sec)
FWHM:	2 (arcsec)	Aperture_radius:	4 (arcsec)

Magnitude	60s	90s	180s
7.00	5714.14	6998.37	9897.18
8.00	3604.77	4414.93	6243.65
9.00	2273.50	2784.46	3937.81
10.00	1432.96	1755.01	2481.96
11.00	901.74	1104.41	1561.87
12.00	565.22	692.25	978.99
13.00	350.90	429.77	607.78
14.00	213.04	260.92	369.00
15.00	123.42	151.16	213.77
16.00	65.95	80.77	114.23
17.00	31.82	38.97	55.11
18.00	14.05	17.20	24.33
19.00	5.87	7.18	10.16

Table 2.2 Signal to Noise Ratio calculations for the O'Mara Telescope.

The focal planes of almost all telescope designs are not flat, meaning that off-axis light reaches focus closer to the objective closer than on-axis light. In the case of visual observing this is not of serious concern as eyepieces can be designed to compensate somewhat and the human eye itself can accommodate for stars near the edge of the field being slightly out of focus. This effect is far more detrimental to CCD imaging since the CCD array being flat cannot coincide exactly with the curved focal plane produced by the telescope optics. This problem is exacerbated in complex optical configurations at fast focal ratios with large detectors. For the O'Mara telescope, the effective depth of focus is 312 microns, calculated according to the equation first given by Sidgwick (1955). The required depth of focus for the CCD detector as implemented before field distortions begin to affect astrometric accuracy is well above this value (around 700 microns) which makes the SCT design suitable for this application.

2.5 The Focuser

Most commercially available SCTs do not perform well for CCD imaging due to the primary mirror being required to change position in the optical path to allow for focusing. By locking the mirror and suppressing this movement, image shift is prevented, but therefore requires that another method of focusing the image must be employed.

In this case, an Optec TCF-S Crayford focuser is attached to the rear cell which results in zero image shift during focusing regardless of telescope orientation.

The Crayford focuser works by applying pressure on a drive shaft which in turn presses against a flat machined surface on the focuser tube. This tube is held in place by sets of bearings on the opposing side and the opposing forces eliminate the play inherent in rack and pinion designs. A diagrammatic representation of this design appears below:

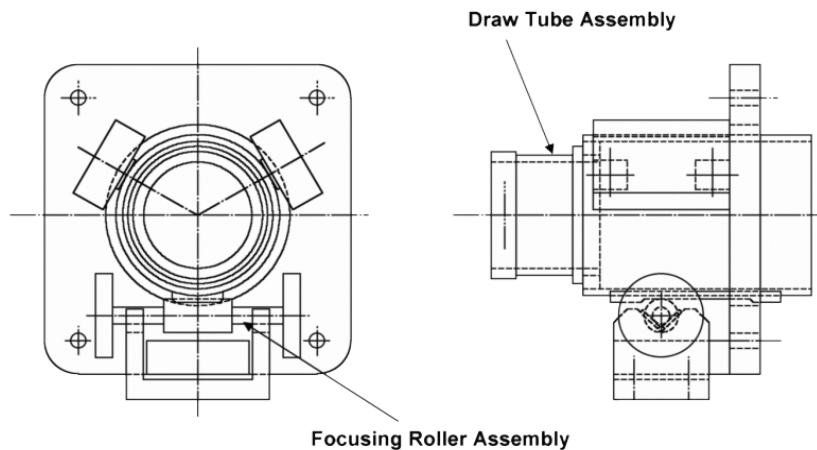


Figure 2.6 The Crayford Focuser design.

Focusing is achieved automatically using the Half Flux Diameter strategy described in Weber and Brady (2001), using the software developed by them and typically within 90 seconds, before each integration. This is necessary in order to allow for changes of the

optical properties of the system which vary throughout an observing session due to temperature variations.

The relationship between the various components of the assembly appears in Figure 2.5

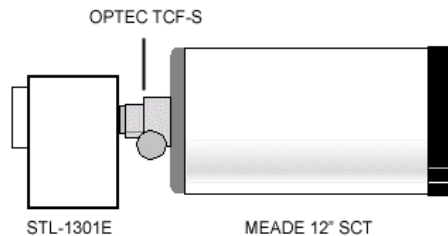


Figure 2.7 The three major components of the optical train of the O'Mara Telescope.

2.6 Dew Control

All catadioptric telescopes suffer from dew forming on the front corrector in high-humidity, low-temperature conditions. To prevent this, a low wattage 12 Volt DC electrical heater strip that wraps around the front of the Meade has been fitted. This warms the optics above the dew point to prevent the formation of dew. Whenever the dome is open for observing, it is in operation.

2.7 Computers

As would be expected, there is a significant amount of computer hardware required in order to implement this type of system. The individual PCs that form part of the system, along with the purpose they each serve follows.

Windows Server PC ("Fry")

This computer performs the majority of the roles related to the operation of the MKO observatory hardware itself. Not only is it physically connected to the actual

components of the observing platform, but it also serves as the hub for inter-communication between most of the software components, primarily using the ASCOM interface standard.

On it is installed The Sky Version 6.0 (for control of the Paramount ME), MaximDL/CCD (operation of the CCD camera) and Automodome (for the control of dome rotation and shutter opening and closing. There are also ancillary support applications such as Atomic Time for synchronization of the computers clock (using the NTP protocol) along with MPO Canopus, should there be a need for data analysis of captured images on-site. The entire observatory could, in theory be controlled from this PC either locally, or by remote terminal emulation across the USQ network or the Internet.

A number of software components are required to interact in order for the system to function. From the outset, a series of possible combinations were considered, but due to the Paramount ME being able to be controlled via The Sky Version 6.0 exclusively, the only option for an operating system environment was a Microsoft Windows based solution. In order to maximize system stability, Microsoft Windows Server 2000 was chosen and this further restricted the choice of other elements. The final list of application software implemented and a brief description their individual role is listed below:

The list of relevant software installed on this machine is as follows:

- *The Sky Version v6.0*: controls the Paramount ME for pointing at and tracking of target objects. (Software Bisque, 2005).
- *Maxim DL v3.00*: controls the CCD camera and filter wheel for CCD imaging. Also performs some level of image processing on the raw images acquired. (Diffraction Limited, 2004).
- *Automadome*: controls the dome enclosure to keep the dome's slit synchronized with the telescope's pointing (Software Bisque, 2005).

- *Astronomer's Control Program (ACP)*: provides interface for software above via ASCOM, and also provides FTP (remote) access for the images that have been requested. (Denny 2005).
- *FocusMax*: Automates focusing of the selected object before each integration using the Half Flux Diameter algorithm. (Weber and Brady, 2001).

Linux Server PC ("Bender")

The Linux server PC inside the dome monitors conditions at the site, and is responsible for environmental monitoring, error detection and mitigation and other system failsafe operations. Should error conditions be detected, it has the ability to override all other on-site systems in order to prevent damage to the observatory.

The principal data collected by this machine is via the Davis Weather Station and Boltwood Cloud detector at the EDG building, with the following readings monitored:

- Ambient External Temperature
- EDG Building Internal Temperature
- Dome Internal Temperature
- Wind Speed and Direction
- Sky Clarity (Cloud)
- Relative Humidity

Communication is provided across the local TCP/IP network and the relevant information presented via standard HTTP web pages. There are also other sensors attached to this machine inside the dome for the detection of dew and rain which serve to prevent damage to any of the equipment due to the ingress of water.

UQ-Based Web Server

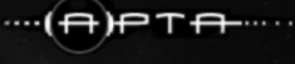
The main interface presented to the user is hosted on a publicly accessible web server located at the St Lucia campus of the University of Queensland. Developed in co-operation with other USQ faculty members, it is a critical component of the final implementation because the process of job submission and simplicity of user interaction is a key factor in the success or otherwise of the project.

This machine accepts user requests for observations, hosts the scheduling engine described in Duncan (2007) and also acts a repository for the images taken by the system. In addition, some post-processing of images is performed automatically should it be requested by the user, the details of which are beyond the scope of this work.

2.8 The Job Submission Process

There are a number of alternatives available to a user when they wish to submit job requests to the O'Mara telescope. These are presented via form style web pages at the observatory website (<http://www.apta.net.au>), and are controlled by user authentication requiring only a modern web browser.


When a visitor arrives at the website, they have a number of options available to them, some of which (such as browsing images made publically available) require no user credentials. A brief example of a simple observation request using an installed filter is outlined below:




powering telescope-net.com

[home](#)
[login](#)
[new account](#)
[gallery](#)
[info](#)
[help](#)

[login >>](#)



HIP 519 (star in constellation Tucana), observed with telescope omara on Thu Jul 23 19:08:10 2009 UTC (9.7 hours ago). [More images...](#)

 [Google Earth stuff.](#)

telescope-net.com

Sign up - log in - see the sky!

telescope-net lets you take pictures of anything in the night sky that is visible to an available telescope. From the comfort of your personal computer, you can access and use telescopes anywhere in the world, simply and easily.

With a login to this website, you can:

- request images of any object in the sky. Stars, galaxies, comets, asteroids, planets - you name it. These will be observed automatically for you. The images will be emailed to you, and will be available for you when you next log in.
- undertake educational astronomy projects, with your school, your class, or individually.
- see real-time information about the telescopes: where they are, what they're doing, what requests are currently scheduled, and what the weather's like.

Figure 2.8 The initial login page of the O'Mara Telescope web site.

For a job to be submitted the user must have an account on the system provided to them previously and once logged in, they are presented with a menu of options.

Observation requests

This allows you to create new observation requests and to examine existing requests. Please choose one of the options below.

- [Look through image galleries.](#)
Look at the most recently observed images, and look through users' image galleries. If you have a public image gallery, you can jump straight to it by clicking [here](#).
- [My gallery.](#)
Look through your images, and manage your public gallery.
- [Submit new imaging requests.](#)
If you would like to submit new imaging requests, either for scheduled observations or for direct control of a telescope.
- [Examine current or old observation requests.](#)
Use this page to examine the status of your current or old imaging requests.
- [Examine telescope schedules.](#)
This option allows you to examine the current working schedules and runlists for telescopes.

Figure 2.9 Top level options available to authenticated users.

By selecting “Submit new imaging requests” a sub menu becomes available allowing for a variety of options related to the type of observation required.

How to submit a new request

This page allows you to choose the type and complexity of your request. Several types are supported at the moment.

Class	Description
• Simple robotic of a bright object	A single image of a bright object, selected from a list of bright objects and robotically observed.
• Simple robotic of any object	A single image of an object, selected by name from our catalog and robotically observed.
• Simple robotic with a filter	A single image of an object, selected by name from our catalog and robotically observed. An arbitrary filter may be specified.
• Double images of moving objects	Two images of a solar system object, selected from a list and robotically observed. The two images will be observed some time apart, so the movement of the object is apparent.
• Multiple images of any object	Multiple images of any objects, selected by name from our catalog and robotically observed. The filter (if any), exposure time and minimum time between images may be specified.

Figure 2.10 Criteria-based observation options available for imaging requests.

As an example, selecting “Simple Robotic with a Filter” presents the following screen which allows for searching of the install catalogues for the desired object.

Make a simple request, with a filter

This page allows you to request a single image of an astronomical object from the catalogue. Requests are submitted to a network of telescopes (rather than an individual telescope), and may be serviced by any telescope in the network. Your request will be scheduled and observed for you, and the results dispatched to you via email. Your request may be moved between telescopes in the network if this might result in your request being serviced more rapidly. You can check the status of your request via the website.

Requests submitted via this page require 1.0 credits. We will attempt to service your request for approximately 7 days. If your request is not successfully observed, your credits will be returned to you automatically when the request is expired.

Please enter the name of the object which you would like to image in the box below. You can enter either the full name, or part of the name. If you do enter only part of the name, please remember to select "partial match", below.

You might also like to try the [advanced search](#) page.
For details on the catalogues searched, [please click here](#).

Catalog name:

Search type: ☒ exact match ☐ partial match

[next step](#)

Figure 2.11 Catalog search input page.

The search results of the object(s) entered are displayed and the user may select from those returned based on the displayed extended information provided.

Object search results

Below are the results of your catalog search. Please click on the object that you wish to observe.

OBJECT NAME	TYPE	RA (J2000.0)	DEC (J2000.0)	CONSTELLATION	MAGNITUDE
M 42	Nebula	05 ^h 35 ^m 23.9 ^s	-05° 27' 00"	Orion	4

try again

Figure 2.12 Catalog search results page.

When confirmed, the system requests a level of priority based on simple quality and efficiency metrics which are briefly explained.

Make a simple request

Please enter additional parameters which tell us how you would like this object observed.

User ID:

Catalog name: M 42

Image quality: ☒ faster ☐ better

Telescope to use: omara (UBVRI filter set)

Notes on the *Image quality* setting:

>> A value of "faster" requests that this observation be scheduled as early as possible. Additionally, the Moon must lie a certain minimum angular distance from the target object. This distance varies with the Moon's phase and can be up to 20 degrees if the Moon is full (please see the FAQ pages for more information on this).

>> A value of "better" requests that this observation be scheduled as close to transit (i.e., as high in the sky) as possible. A minimum altitude of 30 degrees is required, and the Moon must be below the horizon.

Notes on available telescopes:

>> *Telescope "omara"*: This telescope is located at Mt Kent Observatory, a facility of the University of Southern Queensland, Australia

next step

Figure 2.13 Image priority and quality confirmation page.

The desired filter is then selected from a pull-down menu of those available

Make a simple request

Please select the filter to use for this observation.

Catalog name: M 42

Telescope to use: omara

Filter to use:

next step

Figure 2.14 Filter selection page.

Finally, the system provides an overview of the request for final submission.

Make a simple request

This page allows you to review your request before submission.

If you are happy with the parameters of your request, then click below to submit.
You are submitting a request with the following parameters:

User ID: Scott
 Target: M 42
 Image quality: better
 Telescope: omara
 Filter selection: V

[submit this request](#)

[Return to the home page](#)

Figure 2.15 Final job submission confirmation page.

Upon successful submission, the user is provided with details of the request and receives an email confirmation to their nominated email account.

Successful

The requested action was successful.

Your request has been successfully submitted, with request ID of "33877"

[make another request](#)

© 2001-2009 Automated Patrol Telescopes Australia Pty Ltd ([Terms of Service](#)).
 This page view was generated on Sun Jul 26 03:05:11 2009 UTC.
 Content created by NewRequest-Filter1 (Part F) v0.1.0 ([SAROS v2.1](#)).
 Maintained by: info@telescope-net.com

Figure 2.16 Submission receipt page.

Observing request 33877: "M 42"
info@telescope-net.com [info@telescope-net.com]
To: Scott Sindair
Cc:

This is an automated message concerning imaging request 33877 for "M 42".
Details of this request may be viewed at <http://www.telescope-net.com/apta/REQDETAIL/33877>

Status: This request has been submitted for scheduling.
Allocated to observatory: omara

Figure 2.17 Job submission email receipt sent to the user.

Once the submission process has been completed, the scheduling engine processes the job and inserts it in the telescope schedule according the availability of telescopes on the network. At present, only the O'Mara telescope is available for job requests, although future expansion of the network is envisaged.

The results of the subsequent scheduling for this example are shown below:

Observation request details for request number 33877	
Observer	Scott
Observatory	omara
Observation type	Standard
Frame number	43487
Submission engine	
Store directory	00/09/5a
Target name	M 42
Target type	Nebula
Right Ascension (J2000.0)	05 ^h 35 ^m 23 ^s
Declination (J2000.0)	-05° 27' 00"
In constellation	Orion
Approximate visual magnitude	4.0
Source of target coordinates	Standard catalogue
Credits used for this request	1
Exposure time	90.000 s
Request submitted on	Fri Jul 24 03:05:32 2009 UTC
Request expires on	Sun Aug 2 03:03:00 2009 UTC
This request is valid for	8 nights
First night	Sun Jul 26, 2009 (priority 8)
Last night	Sun Aug 2, 2009 (priority 1)
Current status	Submitted
Scheduling policy	Observe as close to transit as possible
Filter specification	V
Is time requested today?	No
Window for Sun Jul 26, 2009	2.0 minutes, starting at 19:15 UTC
Window for Mon Jul 27, 2009	6.0 minutes, starting at 19:11 UTC
Window for Tue Jul 28, 2009	9.0 minutes, starting at 19:07 UTC
Window for Wed Jul 29, 2009	13.0 minutes, starting at 19:03 UTC
Window for Thu Jul 30, 2009	16.0 minutes, starting at 18:59 UTC
Window for Fri Jul 31, 2009	20.0 minutes, starting at 18:55 UTC
Window for Sat Aug 1, 2009	23.0 minutes, starting at 18:51 UTC
Window for Sun Aug 2, 2009	26.0 minutes, starting at 18:48 UTC
Notes	None.

Figure 2.18 Job submission scheduling results.

Detailed planner data for observatory omara on 2009-July-26		
Restriction:	Moon must be below horizon.	
Restriction:	Target must be at altitude of 30° or greater.	
Target above horizon:	07:54	
Length of night:	10:34	
Target visible for:	00:02	
Target observable for:	00:02	
TIME (UTC)	TIME (LMST)	EVENT
03:08	09:31	Target sets below telescope horizon
07:20	13:43	Sunset
08:41	15:05	Astronomical dusk
11:53	18:17	Moonset
19:14	01:39	Target rises above telescope horizon
19:15	01:40	Target observable
19:16	01:41	Astronomical dawn
19:17	01:42	Target no longer observable
20:38	03:04	Sunrise
23:46	06:12	Moonrise

Figure 2.19 Example daily planner detail for the submitted request.

Chapter 3

Results

3.1 General performance

The USQ Mt Kent O'Mara telescope has operated successfully for the majority of clear nights since final implementation in late 2008. Given favorable conditions, over 200 images are routinely captured per observing session, resulting in an efficiency (the proportion of actual integration time during minutes of astronomical darkness) that approaches 60%. This value is based on average exposures over the course of a night of 180 seconds. When exposures are shorter, the efficiency of the system drops due to a increase in the proportion of time being spent acquiring target objects.

Focusing performance is highly efficient, with ambient temperature variations during an imaging session being the primary cause for refocusing to be needed, however a stable observatory environment keeps this requirement to a minimum. On average, the system may re-focus three or four times per night, each operation taking as little as two minutes to complete.

Less than one percent of requested target fields are not able to be automatically plate solved by the system software, displaying a high level of initial pointing performance. The recorded whole sky pointing model displays a RMS error of less than 30 arc-seconds, equivalent to the apparent angular diameter of the planet Jupiter.

Finally, the observatory has demonstrated an ability to function autonomously, to be able to detect the onset of inclement weather and react to appropriately without human intervention.

3.2 Astrometric measurement using the O'Mara Telescope

As stated in the aims and objectives, accurate astrometry is one of the goals of the project. One method by which this can be objectively assessed by is if an observatory is allocated an official IAU observatory code, required by such bodies as the Minor Planet Center before they will accept data relating to the positional measurement of existing (numbered) or newly discovered asteroids and comets.

A documented formal procedure exists to achieve such a designation, and can be accessed via the *Guide to Minor Planet Astrometry* on the IAU Minor Planet Center website located at:

<http://www.cfa.harvard.edu/iau/info/Astrometry.html>

On the evening of the 27th of July 2009, image requests were submitted of two moderately bright main belt asteroids, 3850 'Peltier' and 13166 '1995 WU'. Both of these targets were selected due to their favorable position in the southern sky during the coolest part of the night and visible magnitudes (15 and 16 respectively) which were expected to be within the capabilities of the system.

Once images were successfully captured, data-reduced and stored by the observatory, they were downloaded to the author's personal computer and processed manually using "Astrometrica" (Raab 2010), a commercial application specifically made for the purpose of identifying and reporting minor planets.

After processing, Astrometrica compiled an email submission automatically, and in the correct format for submission to the MPC. As no observatory code had yet been allocated to Mt Kent, 'XXX' appears in the submission below, which effectively requested that a new one be assigned should the observations be of sufficient scientific quality.

```

COD XXX
COM Long. 151 51 18.0 E, Lat. 27 47 51.7 N, Alt. 670m
CON Scott Sinclair, University of Southern Queensland [sinclair@apta.net.au]
OBS Scott Sinclair
MEA Scott Sinclair
TEL 0.30-m Schmidt-Cassegrain + CCD
ACK MPCReport file updated 2009.07.28 16:42:08
AC2 sinclair@apta.net.au
NET UCAC-2
03850      C2009 07 27.44069 19 02 37.07 -20 54 22.3      15.2 V      XXX
03850      C2009 07 27.45890 19 02 36.15 -20 54 28.9      15.3 V      XXX
03850      C2009 07 27.60355 19 02 28.65 -20 55 19.2      15.9 V      XXX
03850      C2009 07 29.36765 19 01 08.63 -21 05 40.8      15.6 V      XXX
03850      C2009 07 29.38705 19 01 07.85 -21 05 47.9      15.3 V      XXX
03850      C2009 07 29.40520 19 01 06.98 -21 05 54.2      15.5 V      XXX
13166      C2009 07 27.44315 18 57 57.46 -39 56 59.1      16.1 V      XXX
13166      C2009 07 27.46146 18 57 56.38 -39 56 58.3      15.8 V      XXX
13166      C2009 07 27.56684 18 57 49.80 -39 56 57.2      16.1 V      XXX
13166      C2009 07 29.37041 18 56 05.99 -39 56 12.7      16.1 V      XXX
13166      C2009 07 29.38962 18 56 04.88 -39 56 12.3      16.0 V      XXX
13166      C2009 07 29.40782 18 56 03.83 -39 56 11.8      15.8 V      XXX

```

Figure 3.1 MPC formal astrometric submission.

The columns of the submission format are self-evident, but briefly each observation is presented as the object designation, date (accurate to within one second), right ascension and declination along with visual magnitude. This data, along with the latitude and longitude of the observatory is used to determine the ability of a system to accurately record to positions of objects against the stellar background.

Observations are required to be made over a number of nights, and as such follow up observations were made of the same targets on the 29th of July 2009 and submitted in the same manner.

The following day, correspondence was received from the MPC advising the MKO Mt Kent had been allocated the IAU code of E22.

Your site is now code E22.

Gareth V. Williams, MS 18, 60 Garden Street, Cambridge, MA 02138,
U.S.A.

Associate Director, Minor Planet Center
gwilliams@cfa.harvard.edu

<http://www.cfa.harvard.edu/iau/mpc.html>

OpenVMS and RISC OS: Refined Choices in Operating Systems

For this code to be allocated on the first attempt indicated that the system was able to achieve positional accuracy to within 1 arc second of moving targets, approaching the limits of its imaging capabilities.

Subsequent observations of minor planets have continued to demonstrate similar results and are discussed in the following chapter.

3.3 Photometry using the O'Mara Telescope

Images obtained with CCD detectors are affected by numerous properties of the observing system, and before they can be used for scientific research must be corrected to take these effects into account. Unlike the task of astrometry, precise photometric measurement requires calibration of the system against known reference stars and subsequent application of so called 'master calibration frames' to the raw images before accurate analysis can be performed. This activity must be carried out on a regular basis as subtle changes in the properties of any optical system will cause the reduced scientific data to be erroneous.

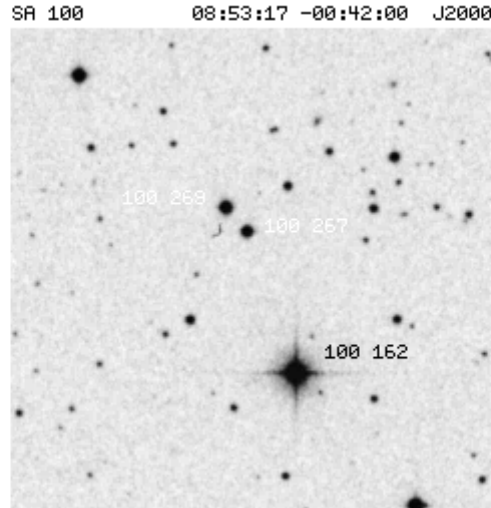
There are many examples in the literature (such as Parimucha1 & Vanko 2005) outlining methods by which this is achieved and the process is well known to the author and shall not be described here.

Once calibrated frames are produced, the generation of light curve graphs can be accomplished by a variety of methods, both manual and more recently by automated software. This software exists as open source applications (such as IRAF, available from <http://iraf.noao.edu/>) and in commercial variants, under a variety of operating system environments.

One such software package is MPO Canopus, developed by The Minor Planet Observer and Palmer Divide Observatory (<http://www.minorplanetobserver.com>). It is primarily used to measure positions of asteroids and determine their rotational periods based on photometric measurement. This is achieved by automatically processing a series of calibrated images, comparing the computed magnitudes of the target object (whether it be a minor planet or star) against known references within the field, and generating a light curve graph for each. Since the software uses multiple reference stars within an imaged field, it is ideal for determining the photometric accuracy of an imaging system across a wide range of magnitude values.

After calibration frames were created for the MKO Mt Kent system, a suitable Landolt (Landolt 1992) field was selected based on air mass for the observation period chosen;

Field Center: RA = 08:53:17 Dec = -00:42:00 (J2000)



Star	RA (J2000)	Dec (J2000)	B-V	U-B	V-R	R-I
100 162	08:53:15	-00:43:29	9.150	1.276	1.497	0.649

Figure 3.2 Landolt Field surrounding SAO 136365.

Fifty frames were acquired during an imaging session on the nights of 13/14th February, 2010 and processed using MPO Canopus to determine the accuracy of the system.

A simplified table of the reduced data is presented below which shows the Julian Date of each observation, the airmass at the time along with the recorded magnitudes of the calibrated frames.

Julian Date	V Magnitude	Air Mass
2455240.71470	9.130	1.156
2455240.71595	9.061	1.158
2455240.71726	9.143	1.16
2455240.71858	9.167	1.163
2455240.71979	9.116	1.165
2455240.72096	9.117	1.167

Julian Date	V Magnitude	Air Mass
2455240.72213	9.119	1.169
2455240.72330	9.082	1.172
2455240.72443	9.158	1.174
2455240.72579	9.135	1.177
2455240.72709	9.093	1.18
2455240.72840	9.118	1.183
2455240.72961	9.126	1.185
2455240.73080	9.142	1.188
2455240.73199	9.180	1.191
2455240.73328	9.161	1.195
2455240.73476	9.121	1.198
2455240.73612	9.106	1.202
2455240.73737	9.140	1.206
2455240.73858	9.131	1.209
2455240.73977	9.128	1.213
2455240.74097	9.134	1.216
2455240.74580	9.200	1.232
2455240.74714	9.180	1.236
2455240.74836	9.197	1.24
2455240.74956	9.199	1.245
2455240.75102	9.153	1.25
2455240.75236	9.127	1.255
2455240.75355	9.165	1.26
2455240.75481	9.210	1.265
2455240.75734	9.160	1.275
2455240.75877	9.182	1.281
2455240.76010	9.179	1.287
2455240.76139	9.197	1.293
2455240.76898	9.364	1.33
2455240.77027	9.357	1.336
2455240.77146	9.246	1.343
2455240.77285	9.196	1.351
2455240.77427	9.199	1.359
2455240.77483	9.264	1.362
2455240.77628	9.216	1.37
2455240.77764	9.164	1.378
2455240.77896	9.178	1.386
2455240.78019	9.253	1.394

Julian Date	V Magnitude	Air Mass
2455240.78142	9.185	1.402
2455240.78270	9.341	1.41
2455240.78755	9.284	1.444
2455240.78896	9.314	1.454
2455240.79024	9.342	1.464

Table 3.1 V Magnitude and Air mass measurements of SAO 136365.

When these results are presented in a graphical format, it becomes apparent that the system achieves a relatively high level of photometric accuracy, within 0.015 and 0.05 of a magnitude of the expected data of the target star in the V band.

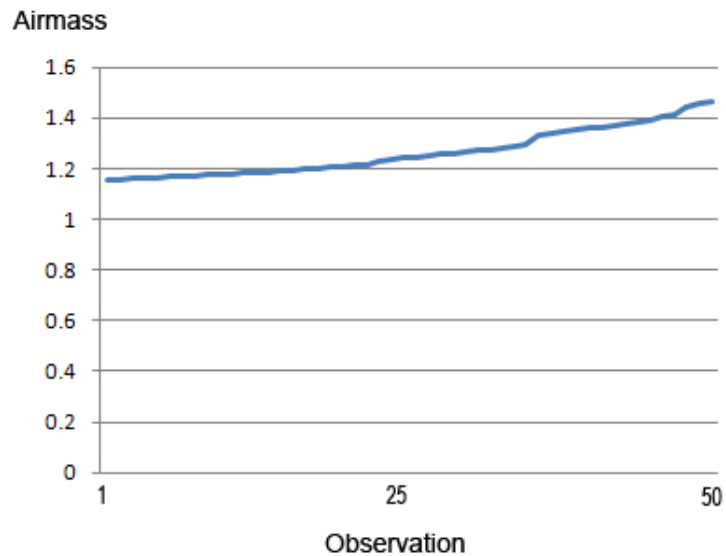


Figure 3.3 Airmass of SAO 136365 during photometric measurement.

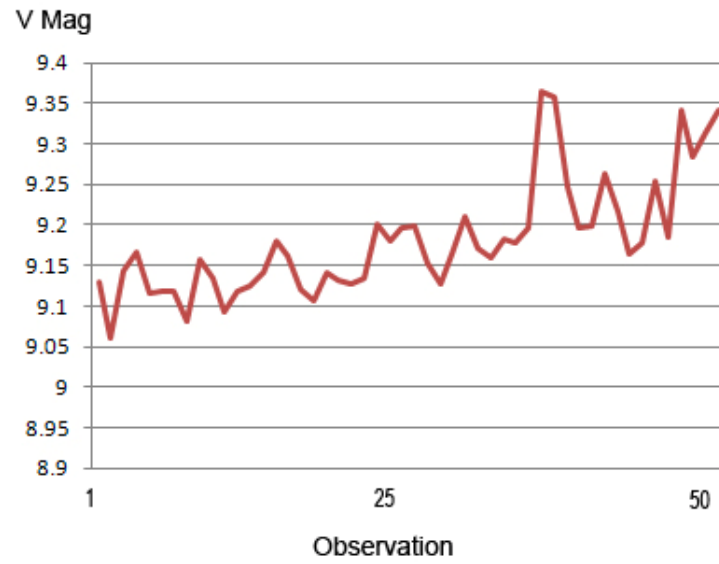


Figure 3.4 V Mag of SAO 136365 during photometric measurement.

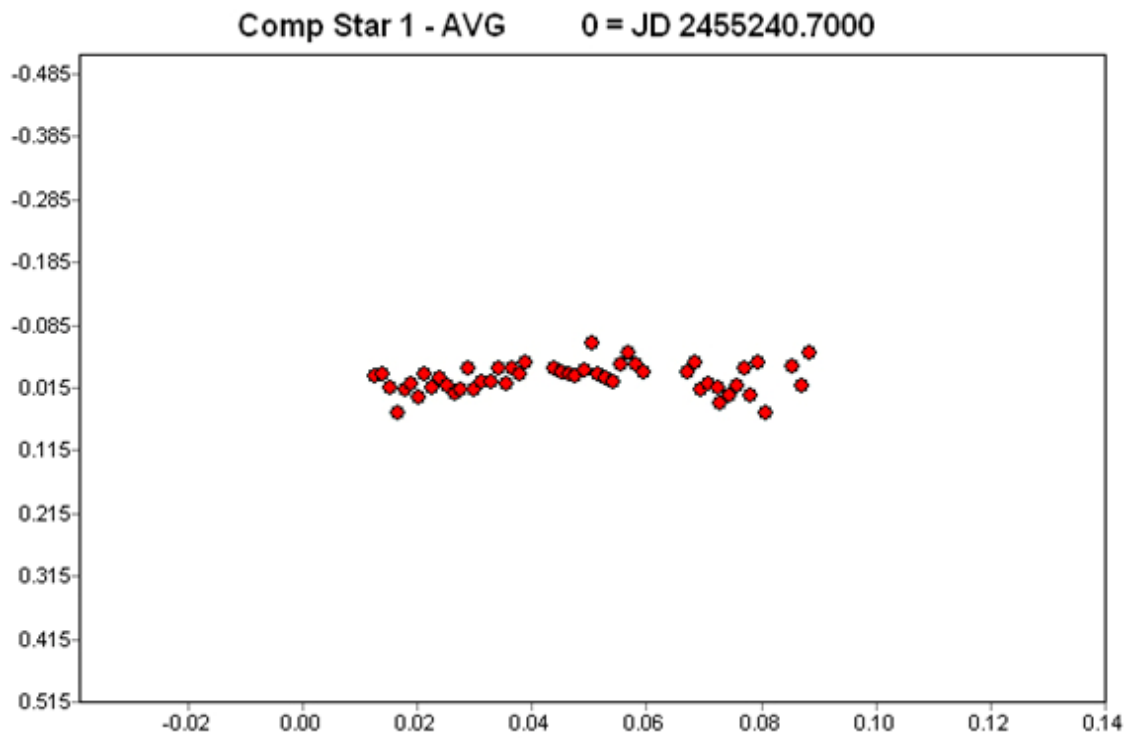


Figure 3.5 Computed photometric variance of SAO 136365.

After these initial results were collected from a star with stable photometric properties, it was decided to test the ability of the system to detect the light curve produced by a variable target.

RZ Pyx (SAO 176601) is a magnitude 9.12(V) early type binary star first identified as variable by Hoffmeister (1936). It is further described by Kinman (1960) and more recently by Malcolm and Bell (1986). It exhibits a regular period of 0.65627 days with a 0.9 magnitude variation in the V band (Kinman 1960), and is well placed for observation from Mt Kent from December to March.

Ephemerides were retrieved online from <http://www.as.up.krakow.pl/o-c/index.php3> and used to construct an observing plan for the nights of 21 and 22 of February 2010. 35 observations were subsequently made, but due to poor weather were not evenly distributed across the two sessions.

The observations were again reduced using MPO Canopus and differential magnitudes formed with respect to comparison stars in the same field. These data were then plotted against existing published data (Breger 1968).

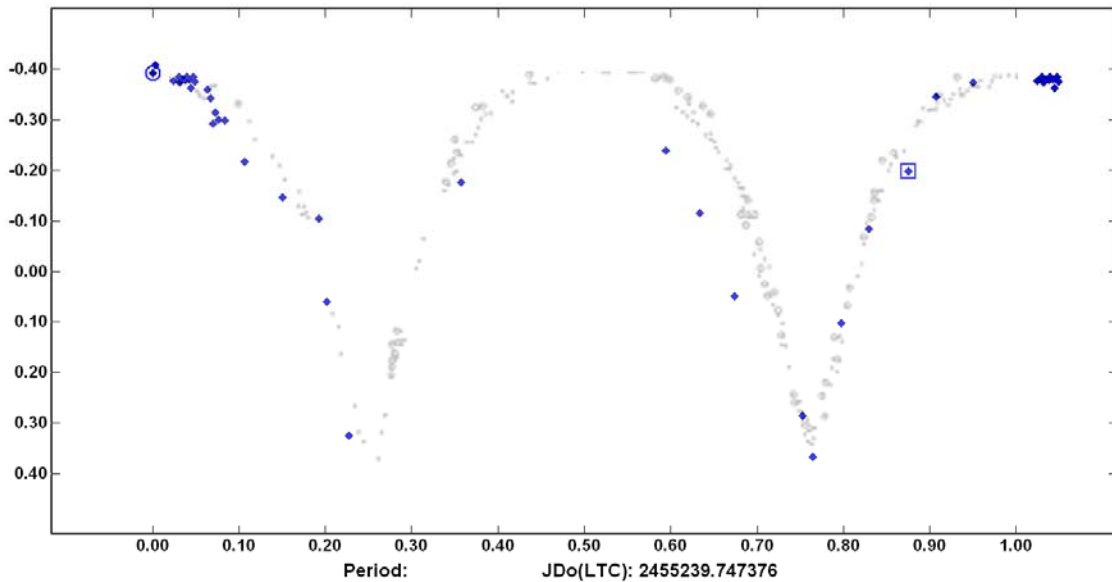


Figure 3.6 Light curve (measured points versus Breger) of RZ Pyx.

Chapter 4

Discussion of Results

4.1 The O'Mara Telescope as a working robotic system

The results presented here demonstrate that the MKO O'Mara telescope system is a fully operational robotic observatory. The facility has in fact been in continual operation over the past two years, with students, USQ staff and the general public capturing images of selected targets on most clear nights at the site.

Further, the observatory has successfully measured the positions of minor planets to sub-arc second accuracy, sufficient to be allocated a permanent IAU observatory code. With a limiting magnitude of approximately 19, the observatory is capable of searching for and detecting faint asteroids.

Another outcome has been the precision measurement of a Landolt standard star (within 0.015 magnitudes) and a periodic variable star, suggesting that the telescope should be capable of determining the rotational periods of active stars using star spot photometry. Present results also act as an encouraging starting point for future work in exo-planet transit photometry.

Overall, the observatory has demonstrated its capacity to monitor moving targets along with objects of varying brightness such as stars. Future improvements to the optics and imaging equipment should enhance the telescope's ability in the area of scientific research.

The value of an observatory such as this when implemented successfully cannot be underestimated. The O'Mara telescope's role in supporting distance education at the University of Southern Queensland provides students the ability to be directly involved

in practical research activities. It is a tool that has the simultaneous properties of accessibility, flexibility and a high level of scientific quality.

As a teaching resource, it is a practical tool for the collection of useful scientific data, which can either be used to confirm or otherwise supplement that gained from other sources, or stand-alone as the basis for the design of observing plans to test new theories.

On the other hand, merely providing access to high-quality imaging equipment to those that may not be otherwise able to access it offers the opportunity to appreciate the wonders of the night sky, so often now degraded to such a degree to be disappointing to all but the most enthusiastic of observers.

Possible uses of this ‘ad-hoc’ ability to request images also include transit phenomena such as asteroid flybys and occultations (Sinclair 2004), unexpected impact events (Wesley 2009) and the appearance of long period comets. Not only are the data adequate from the point of view of speed of acquisition, but it is also of a quality such that it would have the potential to contribute to a larger scale research effort should it be required.

For astrometric tasks, the performance of the system is very high, with residuals being in the order of 0.5 to 1 arc second across the entire sky. This is an important property for such an installation as it provides the opportunity for interesting work to be carried out on a variety of relevant undergraduate research topics such as celestial mechanics, asteroid light curve determination and general astrometry of solar system bodies.

When used as a research instrument in this manner, the system has far greater functionality and therefore potential usefulness to the end user. The astrometry example herein demonstrates that the system is capable of automating a complex and extended set of requests, and greatly improves the degree to which the observatory can be utilized by single researcher or indeed a larger group.

By employing efficient and flexible scheduling, observatory output is maximized, resulting in a higher output of usable data than would otherwise be possible using traditional approaches.

4.2 Future teaching and research activities

It is recommended that the O'Mara telescope be utilized primarily for undergraduate activities as follows:

- A program that tasks students with the acquisition, interpretation and presentation of data collected with the telescope as part of their coursework. The outcome would be a student report equivalent to that prepared as if they were in a laboratory environment.
- The program would be targeted at undergraduate students, however would also be of value and could be offered to high school level students and their teachers as part of wider outreach activities.
- The science component would comprise of a choice between asteroid detection and variable star photometry. Suitable software for these activities already exists, notably ImageJ which has been extensively used for astronomy.
- The program could be implemented and be assessed as part of existing courses offered by the University of Southern Queensland, and its success evaluated within the current framework of student feedback and course review mechanisms by academic staff.

Another possible area of research (and perhaps the most interesting due to recent public focus on the near earth object threat) is that related to the study of asteroid light curves.

Due to unseasonal weather patterns during the final stages of the project, a planned observational program of binary asteroid candidates was unable to be undertaken and

instead is scheduled for the August-October 2010 observing window. The activities that will make up this program are outlined in the following narrative.

For the compilation of asteroid light curves, the CCD camera would be used with the V filter applied which maximises the sensitivity of the photometric array. As shown earlier, the KAF-1301E reaches a maximum quantum efficiency of 72% at around 550nm which corresponds to the 'V' band of the installed filter set.

Possible targets have been identified firstly by selecting asteroids for which good rotational data was readily available, then entering them in to The Sky software to ensure they would be visible at the observatory. Exposure times are to be fixed at 30, 60, 120 and 180 seconds depending on the expected brightness of the object being observed and other factors such as sky brightness, which is affected by the lunar phase etc. These of course can be adjusted should the need arise, and can be entered as any value from .001 to 3600 seconds as required.

The following list of potential targets has been compiled as available for study in the coming months:

Object	V Magnitude
(3105) Stumpff	15.1
(3850) Peltier	15.9
(6384) Kervin	14.5
(13166) 1995 WU1	16.0

Table 4.1 Potential binary asteroid targets for August-October 2010.

Each object is to be imaged as part of a time series, and by allowing changes in the background field, confirmation of photometric calibration to standard R-band magnitudes using sufficient stars from the Landolt standards (Landolt 1992) is possible. These standards are imaged at air-masses between 1.1 and 2.5 during the observation window and extinction values derived for the purpose of calibration. Since all images are taken with the 'V' filter, they are calibrated as for the Cousins R system.

Of potential future interest is the search for new minor planets using alternative techniques to those described here such as time delay integration. Further work to explore its possible inclusion in research activities is expected as the site is included in more undergraduate programs.

Chapter 5

Conclusions

The details and capabilities of the O'Mara Telescope at the USQ Mount Kent Observatory have been described. It has been shown that an installation which can obtain high quality images using modest commercial equipment need not require the presence of an observer at the telescope, since the data acquisition can be performed robotically.

The system can routinely make in excess of 200 observations per night, largely due to the combined efficiencies of each sub-component (hardware, acquisition software and most importantly the scheduling engine), but also due to a high degree of reliability as would be expected from commercially supported instruments. Furthermore, this can be done extremely economically, with minimal system downtime and little human intervention.

The observatory has been constructed, tested and implemented successfully within the budget constraints of a regional university faculty and would not be beyond the resources of an individual or small astronomy collective.

In contrast to other pragmatic approaches, solving the overall problem of interoperability rather than each sub-task individually has resulted in a working implementation of a robotic observation platform, that satisfies that aim and objectives of the project and provides a solid foundation for future enhancement.

List of References

Breger, M. 1968, Photoelectric *Observations of DS Andromedae and RZ Pyxidis*. PASP, Vol. 80, p.417

Carter, B. (2008) *Telescopes at Mt Kent Observatory* 2007
University of Southern Queensland, viewed 1 July 2008,
<http://orion.mko.usq.edu.au/telescopes/index.html>

2006 Census QuickStats : Toowoomba Statistical District (QLD) 2008
Australian Bureau of Statistics, viewed 20 March 2009,
<http://www.censusdata.abs.gov.au>

Climate Statistics for Australian Locations: Toowoomba 2007
Australian Government Bureau of Meteorology, viewed 5 July 2008,
http://www.bom.gov.au/climate/averages/tables/cw_041103.shtml

Climate Statistics for Australian Locations: Toowoomba 2007
Australian Government Bureau of Meteorology, viewed 5 July 2008,
http://www.bom.gov.au/climate/averages/tables/cw_041103.shtml

Castellano, T. et al. 2004, *The Journal of the American Association of Variable Star Observers*, 33, 1, 1.

Duncan, A. R. 2007. Observation Scheduling for a Network of Small-Aperture Telescopes. *Publications of the Astronomical Society of Australia* **24**, 53–60.

Everett, M., Howell, S., 2001, *A Technique for Ultrahigh-Precision CCD Photometry*. PASP, 113, 1428.

Hayes, D. S., and Genet, R.M., (eds.) 1989, *Remote-Access Automatic Telescopes* (Mesa, AZ: Fairborn Press).

Henden, A. A., & Kaitchuk, R. H. 1990, *Astronomical Photometry* (Richmond: Wilmann-Bell)

Henry, W. H., *ATIS Dispatch Scheduling of Robotic Telescopes*, ASP Conference Series, Vol. 87, 1996.

Hoffmeister, C., 1936. *Astr. Nachr.*, 258, 39.

Honeycutt, R.K., Kephart, J.E., and Hendon, A.A. 1978, *Sky and Telescope*, 56, 495.

- Howell, S.B, 1989, *Two-dimensional aperture photometry - Signal-to-noise ratio of point-source observations and optimal data-extraction techniques*. PASP, Vol. 101, p.616.
- Kinman, T.D., 1960. *Mon. Not. R. astr.Soc. Sth Afr.*, 19, 62.
- Landoldt, A.U., 1992, *UBVRI photometric standard stars in the magnitude range 11.5-16.0 around the celestial equator*. Astronomical Journal, 104, 340.
- MPC Guide to Minor Body Astrometry*, Minor Planet Center, Cambridge, MA, viewed 20 July, 2009,
<http://www.cfa.harvard.edu/iau/info/Astrometry.html>
- Malcolm, G. J. & Bell, S.A., 1986. *Mon. Not. R. astr.Soc. Sth Afr.*, 45, Nos 1 & 2.
- Moller, P., 1996, *Astronomical seeing measurements using a differential image motion monitor*. (Toowoomba: USQ Press).
- Parimucha1, S. & Vanko, M. 2005, *Photometry of the variable stars using CCD Detectors*, Contrib. Astron. Obs. Skalnat'e Pleso 35, 35 – 44, (2005)
- Raab, H., 2009, *Shareware for research grade CCD Astrometry*
<http://www.astrometrica.at/>
- Sidgwick, J.B.,1955, *Amateur Astronomer's Handbook*. (London:Faber & Faber)
- Sinclair, S.V., 2004, *Asteroid (4179) Toutatis to Pass Closely By Earth on Wednesday, September 29, 2004.*, viewed 20 July 2009
<http://neo.jpl.nasa.gov/news/news144.html>
- Truebold, M. and Genet, R.M., 1985, *Microcomputer Control of Telescopes* (Richmond: Willmann-Bell).
- Weber, L., and Brady, S., *Fast Auto-Focus Method and Software for CCD-based Telescopes*, viewed 20 July, 2009
<http://users.bsdwebsolutions.com/~larryweber/ITSPaper.htm>
- Wesley, A. 2009, *Impact mark on Jupiter.*, viewed 21 July 2009
<http://jupiter.samba.org/>
- Wood, P.R., Rodgers, A.W., Russell, K.S. 1995, *Seeing Measurements at Freeling Heights and Siding Spring Observatory*, Astronomical Society of Australia, vol. 12, pp. 97-105.

Bibliography

Davis Instruments. <http://www.davisnet.com>

Fattal, R., Lischinski, D., and Werman, M. 2002. Gradient domain high dynamic range compression. ACM Transactions on Graphics 21, 3 (Proc. SIGGRAPH 2002), 249--256.

Genet, Russell., et al. Robotic Observatories. (Mesa, AZ: Autoscope Corporation, 1989).

Henry, G. W., & Hall, D.S., ATIS and the Evolution of Automatic Telescopes. I.A.P.P.P. Communications No. 52, p82-84, Summer 1993, (NASA Astrophysics Data System).

Optec Inc. Technical Manual for Theory of Operations and Operating Procedures for and of the TCF-S Focuser. Accessed 10 December 2007.
<http://www.optec.inc>

Mallama, A. 1993. The Limiting Magnitude of a CCD Camera. Sky & Telescope., Vol. 85, No. 2, p. 84 – 86

Montenbruck, Oliver. Practical Ephemeris Calculations. (Berlin: Springer-Verlag 1989).

Romanishin, W. An Introduction to Astronomical Photometry using CCDs. (OK: University of Oklahoma 2001).

Rutten, H. & van Venrooij, M. Telescope Optics. (Richmond VA: Willman-Bell 1998).

Santa Barbara Instrument Group.
<http://www.sbig.com>

West, Mark. Astronomical Site Survey for Future Telescopes on the Darling Downs. (QLD: University of Southern Queensland 1995).

Wodaski, Ron. The New CCD Astronomy. (Duvall WA: New Astronomy Press 2002).

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Glossary of Terms

API	Application Programming Interface.
Astrometry	The branch of astronomy that relates to precise measurements and explanations of the positions and movements of stars and other celestial bodies.
Differential Photometry	Measurement of the brightness of a celestial object compared to a known source, e.g. standard magnitude star
Ephemeris	An ephemeris is a tabulation of computed positions and velocities (and/or various derived quantities such as right ascension and declination) of an orbiting body at specific times.
Geocentric	Refers to a reference system centered at the Earth, or viewed or measured as from the center of the Earth.
Light Curve	A light curve is a chart that graphs the variation in magnitude with time.
Minor Planet	Relatively small celestial bodies composed of metals and rocks that revolve around the sun, a.k.a asteroid and planetoid.
MPC	Minor Planet Center, the organization responsible for the collection, computation, checking and dissemination of astrometric observations and orbits for minor planets and comets.
Photometry	The measurement of the flux or intensity of an astronomical object's electromagnetic radiation.

Equations

- 1) The surface area of the telescope objective.
- 2) The ratio of the 14" Celestron to the 12" Meade optical tube assemblies.
- 3) The resolving power of a given aperture.
- 4) Signal to Noise Ratio of a Charge-Coupled Device.